INTERACTION OF O_3 WITH SALINITY ON VEGETATION

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Final Report

Prepared for the

California Air Resources Board

Contract No. A4-156-33

July 3, 1986 - January 3, 1987

March 1987

Statewide Air Pollution Research Center
University of California
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and

U.S.D.A. Salinity Laboratory
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ABSTRACT

The interaction between photochemical oxidants (primarily O_3) and salinity on vegetation was evaluated in the field. Alfalfa, an important crop grown in the Sacramento and San Joaquin Valleys and Southern California was the test plant. Two cultivars, one salinity resistant "U.C. Salton," but of unknown O_3 sensitivity, and a second salinity sensitive and moderately sensitive to O_3 "Moapa," were grown at three salinity levels in soil plots at the U.S.D.A. Salinity Laboratory, Riverside, California. Salinity treatments were imposed by irrigating with waters having electrical conductivities (EC) of 0.7, 3 and 6 dS m^{-1} which resulted in saturated-soil-extract conductivities (EC_e) of approximately 1.9, 6.2 and 9.3 dS m^{-1}, respectively, to evaluate the effects of excess salinity in the absence or presence of O_3, plants were exposed in open-top chambers to filtered or unfiltered air at ambient O_3 concentrations continuously over approximately four and one-half months from July through mid-November 1985. Important physiological measurements including net photosynthesis, stomatal conductance, water potential, and tissue elemental content, were made to determine the metabolic basis for the salinity-O_3 interaction. The dry matter production and distribution within the plants were evaluated at four harvests by measuring fresh weight, dry weight, number of nodes per stem, number of empty nodes per stem, and height.

There was no overall significant interaction between ambient O_3 and salinity. There was little effect of O_3 itself on growth, yield, or physiology; only on leaf injury as measured as percent empty nodes for three of the four harvests. For two of these harvests, leaf injury occurred to the same extent in ambient and filtered chambers regardless of the salinity level; for the other harvest injury was reduced with increasing salinity. Salinity was much more detrimental than O_3 in affecting plants, causing occasional reductions in fresh weight, dry weight, increased percent dry weight, decreased percent empty nodes, decreased height, decreased photosynthetic rates, more negative stem water pressure potential, and altered elemental content. There were large differences in growth and yield between the two cultivars. A large difference in alfalfa growth and physiology appeared to develop between chambers and outside

plots as the growing season progressed. Outside plants tended to have higher fresh and dry weights, a higher percent dry weight, were shorter, had fewer empty nodes, and altered elemental content compared to ambient chamber plants.

Overall this study indicated that salinity can reduce O_3 injury to plants, but that there was little interaction between O_3 and salinity on plant growth, yield, or physiology. At the levels tested, salinity would affect plants much more than O_3 in areas where both stresses occur. Experimental designs which use open-top chambers to evaluate air pollution x other environmental stress interactions may not adequately represent field conditions due to complex interactions between the chambers themselves and the stresses.

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DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

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SUMMARY AND CONCLUSIONS

Vegetation growing under field conditions is rarely exposed to a single environmental stress: generally, several stresses occur simultaneously. Plant responses to a single environmental stress such as air pollution are, in fact, modified by soil or climatic factors. Thus, the quantitative effects of air pollutants documented under closely controlled experimental conditions, e.g., photosynthetic changes, mineral content, or dry matter production, may not reflect the effects occurring under field conditions.

Photochemical oxidants (primarily O_3) have been shown to affect the physiological response, growth and yield of many crops. Both the California Air Resources Board (CARB) and U. S. Environmental Protection Agency have funded research to quantify these effects, but only for plants growing under optimum field conditions. This is a necessary primary step to establish baseline response curves for different air pollutant levels. However, research is now necessary to interpret the predicted plant responses based on actual field conditions by considering the most likely environmental stresses which may affect the plants.

Salinity is an existing or potential threat to crop production in most of the irrigated soils of California. It is estimated that crop yields are significantly reduced on at least one-third of the irrigated acreage. Much of this acreage is also subject to detrimental effects of air pollution.

Salinity has been shown to reduce air pollutant injury to crops under laboratory conditions. Hoffman and co-workers at the USDA Salinity Lab in Riverside, CA, showed that a moderate, not injurious, level of salinity reduced O_3 effects on plant injury and yield compared to nonsaline O_3-exposed crops, including alfalfa, pinto beans and beet. High salinity levels reduced O_3 injury but the salinity itself caused large reductions in yield. Bytnerowicz and Taylor found that salinity decreased O_3 injury in snap beans. High salinity, however, had no effect on O_3-induced reductions in snap bean dry weight. In these salinity-air pollutant studies, the beneficial effects of salinity in reducing air pollutant effects were attributed to salinity-pollutant interactions in causing stomatal closure and, therefore, less pollutant uptake.

There has been little physiological research investigating the metabolic basis for any form of soil environment stress and O_3 interaction. Generally, stomata close to a greater extent with the combination of either salinity or water stress and O_3 than with either single factor. The resulting decrease in gas exchange is believed to reduce the uptake of O_3 into leaves, with subsequent reductions in visible injury symptoms attributable to O_3, or the O_3-induced reduction in yield. In the field an O_3 x salinity effect on stomatal closure over a long period of time could significantly affect the uptake of CO_2, and hence the production of plant dry matter via photosynthesis. However, there are no reports of measurements for photosynthesis in salinity-O_3 interaction studies. Furthermore, there has been little research reported on the effects of O_3 alone on photosynthesis. Coyne and Bingham described an O_3-induced reduction in net photosynthesis for southern California pine stands. If crops are also affected by O_3, the added decrease in CO_2 uptake with saline water could produce a synergistic effect on yield.

Research has only recently been initiated to investigate the effects of salinity by itself on plant photosynthesis. To date, salinity has not been found to affect photosynthetic rates directly, but affects plant productivity primarily through inhibited leaf expansion. This inhibited expansion could be especially important in affecting the pollutant transport into leaves, and, hence, relative sensitivity to air pollutants.

The U.S.D.A. Salinity Laboratory has the controlled salinity treatment plots necessary for a careful investigation of the physiological growth and yield effects of salinity in vegetation. The Statewide Air Pollution Research Center has the facilities for careful control of air pollutant exposures, as well as tools for investigating the responses of plants. Together, research groups from both agencies provided a well designed experiment to quantitatively study the interaction between these two important plant stresses in California: salinity and O_3 air pollution.

Objectives. The primary objective of this study was to determine the effects of O_3 on vegetation in the absence and presence of three levels of salinity stress. Two alfalfa cultivars including a newly developed salinity-resistant cultivar, were tested under field conditions.

Subordinate objectives of the study included:

(1) Obtain physiology data to understand the mechanism for the air pollutant-salinity effects to increase the applicability of the results for other species and conditions.

(2) Establishment of dose-response curves for plant productivity in response to O_3 and salinity alone and in combination.

(3) Determine whether salinity resistant cultivars of plants are also resistant to O_3.

The interaction between ambient O_3 and salinity on vegetation was evaluated in the field. Alfalfa, an important crop grown in the Sacramento and San Joaquin Valleys and Southern California, was the test plant. Two cultivars, one salinity resistant "U.C. Salton," but of unknown O_3 sensitivity, and a second salinity sensitive and moderately sensitive to O_3 "Moapa," were grown at three salinity levels in soil plots at the U.S.D.A. Salinity Laboratory, Riverside, California. Salinity treatments were imposed by irrigating with waters having electrical conductivities (EC) of 0.7, 3 and 6 dS m^{-1} which resulted in saturated-soil extract conductivities (EC_e) over all treatments and harvests of approximately 1.8, 6.4 and 9.6 dS m^{-1}, respectively. The 1.8 dS m^{-1} conductivity level represented soils with no salinity problem. The 6.4 and 9.6 dS m^{-1} conductivity levels represented soils with salinity problems as found in approximately 29% of the irrigated agricultural areas of California. To evaluate the effects of excess salinity in the absence or presence of O_3, plants were exposed in open-top chambers to filtered or unfiltered air at ambient O_3 concentrations continuously over approximately four and one-half months from July through mid-November 1985. Important physiological measurements including net photosynthesis, stomatal conductance, water potential, and tissue elemental content, were made to determine the metabolic basis for the salinity-O_3 interaction. The dry matter production and distribution within the plants were evaluated at four harvests by measuring fresh weight, dry weight, number of nodes per stem, number of empty nodes per stem, and height.

There was no overall significant interaction between ambient O_3 and salinity. There was little effect of O_3 itself on growth, yield, or physiology. Ozone primarily caused leaf injury as measured as percent empty nodes for three of the four harvests. For two of these harvests,

leaf injury occurred to the same extent in ambient and filtered chambers regardless of the salinity level; for the other harvest injury was reduced with increasing salinity. There were also O_3 effects on total fresh weight, total dry weight, and height - but only for one harvest each. Salinity was much more detrimental than O_3 in affecting plants, causing occasional reductions in fresh weight, dry weight, increased percent dry weight, decreased percent empty nodes, decreased height, decreased photosynthetic rates, more negative stem water pressure potentials, and altered elemental content. There were large differences in growth and yield between the two cultivars. A large difference in alfalfa growth and physiology appeared to develop between chambers and outside plots as the growing season progressed. However, it could not be analyzed statistically because of differences in soil salinity levels between these two treatments. Outside plants tended to have higher fresh and dry weights, a higher percent dry weight, were shorter, had fewer empty nodes, and altered elemental content compared to ambient chamber plants.

Conclusions

This study was complex because of changes in plant response with salinity, O_3, cultivar, chambers, and season. However, the following generalizations are indicated by the study.

1. Increased soil salinity did not interact with ambient O_3 to decrease growth or yield below that caused by the individual stresses.

2. The only interaction between soil salinity and O_3 was decreased O_3-induced leaf senescence with high levels of soil salinity at one harvest.

3. Open-top field chambers themselves had adverse effects on plant growth, especially with cooler, overcast weather conditions. These chamber effects can overshadow any single treatment effects or interactions.

4. Crop cultivars differed in their response to stresses, thus, results with only one cultivar produce an incomplete picture of possible pollutant and environmental factor interactions.

5. Alfalfa did not respond well in chamber studies in cooler months such as the fall. The stems tended to elongate in chambers compared to

outside, resulting in lodging of plants, and associated apparent decreases in yield.

6. Repeated physiological measurements are required for accurate assessment of the metabolic basis for any interaction responses.

RECOMMENDATIONS

This study indicated the complexity of studies investigating interactions between air pollutants and other stress factors in the field. Future studies should minimize the influence of other factors on plant response to maximize the potential to detect statistically significant stress interactions. Recommendations to accomplish this include:

1. Investigate stress interaction using an exposure system that minimizes environmental modification due to chamber walls, air movement, etc. Open air release (ZAP) systems or air exclusion systems are recommended over field chambers.

2. Conduct the study only during a single season of the year, i.e., summer rather than spring or fall, to minimize influence of seasonal environment on the stress interaction.

3. Increase levels of each factor beyond two.

4. Intensively investigate important physiological responses to the stresses on a frequent basis.

I. INTRODUCTION

Vegetation growing under field conditions is rarely exposed to a single environmental stress: generally, several stresses occur simultaneously. Plant responses to a single environmental stress such as air pollution are, in fact, modified by soil or climatic factors. Thus, the quantitative effects of air pollutants documented under closely controlled experimental conditions, e.g., photosynthetic changes, mineral content, or dry matter production, may not reflect the effects occurring under field conditions.

Photochemical oxidants (primarily O_3) have been shown to affect the physiological response, growth and yield of many crops. Both the California Air Resources Board (CARB) and U. S. Environmental Protection Agency (10,11,12) have funded research to quantify these effects, but only for plants growing under optimum field conditions. This is a necessary primary step to establish baseline response curves for different air pollutant levels. However, research is now necessary to interpret the predicted plant responses based on actual field conditions by considering the most likely environmental stresses which may affect the plants.

Alfalfa is an important crop which is sensitive to O_3. The major areas of alfalfa production in California, the San Joaquin Valley, the Sacramento Valley, and portions of northern California (6) have moderate levels of photochemical oxidants (primarily O_3) which may exceed 0.10 ppm O_3 on 5-10 days per year. The sensitivity of alfalfa to O_3 was investigated at the University of California, Riverside (UCR) (25,27,32,33). Two cultivars of alfalfa were tested by Thompson et al. (32), with total dry weights of Hayden and Eldorado were reduced by 42 and 33% respectively, following exposure to nonfiltered versus filtered air. Oshima et al. (27) tested the cultivar Moapa in plots throughout the Los Angeles Basin, and predicted yield loss of about 33% with 357 hours above 0.10 ppm O_3.

Salinity is an existing or potential threat to crop production in most of the irrigated soils of California (5). It is estimated that crop yields are significantly reduced on at least 29% of the irrigated acreage with electrical conductivity of saturated-soil extracts (EC_e) >4 dS m^{-1} (2). Parts of this acreage also are subject to detrimental effects of air pollution.

Although serious crop losses from salt can be minimized by proper management, it is impractical to remove all excess salts from the soil. Salt concentrations, especially calcium (Ca) and sodium (Na) increase in irrigated soils when insufficient water is applied to leach the salts out of the root zone (28). With appropriate leaching and drainage, the salt concentrations in the soil can be controlled to levels suitable for a given crop. Agricultural crops vary widely in their tolerance to soil salinity (19,21), therefore, salinity levels can be maintained at different levels for different crops. In crops moderately sensitive to salinity (e.g., alfalfa), productivity losses can be expected when soil salinities exceed 2 dS m^{-1}.

Salinity has been shown to reduce air pollutant injury to crops under laboratory conditions. Hoffman and co-workers at the USDA Salinity Lab in Riverside, CA, showed that a moderate, not injurious, level of salinity reduced O_3 effects on plant injury and yield compared to non-saline O_3-exposed crops, including alfalfa, pinto beans and red beet (14,15,20, 21,22,23). High salinity levels reduced O_3 injury but the salinity itself caused large reductions in yield. Bytnerowicz and Taylor (4) found that salinity decreased O_3 injury in snap beans. High salinity, however, had no effect on O_3-induced reductions in snap bean dry weight. In these salinity-air pollutant studies, the beneficial effects of salinity in reducing air pollutant effects were attributed to salinity-pollutant interactions in causing stomatal closure and, therefore, less pollutant uptake (4).

Although the effects of O_3 have not been evaluated on crops growing under saline field conditions, investigators at the U. S. Salinity Lab have observed that O_3 injury is greater on crops grown on non-saline soils than on saline soils (E. V. Maas, personal communication). There have been a few recent reports of other environmental stresses, i.e., water stress from decreased irrigation affecting crop sensitivity to O_3 in the field as part of the National Crop Loss Assessment Network (NCLAN) Project (1). Heggestad et al. (13) found that a mild water stress acted synergistically to increase injury from ambient O_3 to soybeans. Temple et al. (31) reported, conversely, that slight water stress decreased ambient O_3 injury to cotton at Shafter, CA, and that water stress itself significantly decreased yields. Both of these studies were conducted in open-top

field chambers under ambient growing conditions with water stress treatments imposed by withholding irrigation water. Adams et al. (1) calculated that water stress can reduce O_3-induced yield losses by up to 40%. The greatest decrease in yield losses from O_3 occurred where yield reductions caused by O_3 alone were the greatest.

There have been no similar field studies of salinity-pollutant interactions. The results of Hoffman et al. (15) indicated that alfalfa would be subject to the interactive effects of O_3 and salinity under field conditions, and would be an ideal test crop to evaluate the interaction. The unique facilities of the Statewide Air Pollution Research Center and the U. S. Salinity Laboratory combined in this cooperative project provide an ideal opportunity to evaluate the effects of this interaction on crop physiology and yield.

There has been little physiological research investigating the metabolic basis for salinity or drought stress and O_3 interactions. Generally, stomata close to a greater extent with the combination of either salinity or drought stress and O_3 than with either single factor (4,24). The resulting decrease in gas exchange is believed to reduce the uptake of O_3 into leaves, with subsequent reductions in visible injury symptoms attributable to O_3, or the O_3-induced reduction in yield (14). In the field an O_3 x salinity effect on stomatal closure over a long period of time could significantly affect the uptake of CO_2, and hence the production of plant dry matter via photosynthesis. However, there are no reports of measurements for photosynthesis in salinity-O_3 interaction studies. Furthermore, there has been little research reported on the effects of O_3 alone on photosynthesis. Coyne and Bingham (8) described an O_3-induced reduction in net photosynthesis for southern California pine stands. If crops are also affected by O_3, the added decrease in CO_2 uptake with saline water could produce a synergistic effect on yield.

The effects of salinity by itself on plant gas exchange have been studied for some time (9), but the interpretation of the data is complicated by the methods used and the bases of calculation (5). To date, salinity has not been found to affect photosynthetic rates directly, but affects plant productivity primarily through inhibited leaf expansion (5). This inhibited expansion could be especially important in affecting the pollutant transport into leaves, and, hence, relative sensitivity to air pollutants.

The U.S.D.A. Salinity Laboratory has the controlled salinity treatment plots necessary for a careful investigation of the physiological growth and yield effects of salinity in vegetation. The Statewide Air Pollution Research Center has the facilities for careful control of air pollutant exposures, as well as tools for investigating the responses of plants. Together, research groups from both agencies can provide a well designed experiment to quantitatively study the interaction between these two important plant stresses in California: salinity and O_3 air pollution.

Objectives. The primary objective of this study was to determine the effects of O_3 on vegetation grown on nonsaline soil and at two levels of salinity stress. Two alfalfa cultivars including a newly developed salinity-resistant cultivar, were tested under field conditions.

Subordinate objectives of the study included:

(1) Obtain physiology data to understand the mechanism for the air pollutant-salinity effects to increase the applicability of the results for other species and conditions.

(2) Establishment of dose-response curves for plant productivity in response to O_3 and salinity alone and in combination.

(3) Determine whether salinity resistant cultivars of plants are also resistant to O_3.

II. METHODS

A. Pollutant Exposures and Monitoring

Plants were exposed to ambient O_3 within 3.0 m diameter portable open-top field chambers of the NCLAN design (11), but with a modified baffle at the top to prevent ambient air incursion (16). The open-top chambers were located over twelve plots and six plots were maintained as open area controls (Figure 1). The chambers were placed in the center of the plot over the plants immediately after the first harvest on July 11, 1985, 12 weeks after planting. The plants outside of the chamber were maintained to insure similar competitive root growth for plants within and next to the wall of the chamber.

Target O_3 and salinity treatments are shown in Table 1. They consisted of 6 open plots exposed to ambient air without chambers, 6 plots exposed to ambient air in chambers, and 6 plots that receive filtered, O_3-free air in chambers. Each treatment was replicated twice. Chamber treatments were randomly assigned to the 12 plots.

Chamber exposures were continuous for seven days/week until plant harvest. Ozone was monitored with a Dasibi ultraviolet O_3 analyzer. The data was collected with an ISAAC® interface and Apple® IIe computer system. There were O_3 sample tubes in each chamber and in outside control

Table 1. Target Ozone and Salinity Treatments

Treatment	System	Pollutants	Salinity dS m^{-1}
1	Open area	Ambient air	0.7
2	Open area	Ambient air	3.0
3	Open area	Ambient air	6.0
4	Chamber	Ambient air	0.7
5	Chamber	Ambient air	3.0
6	Chamber	Ambient air	6.0
7	Chamber	Filtered air	0.7
8	Chamber	Filtered air	3.0
9	Chamber	Filtered air	3.0

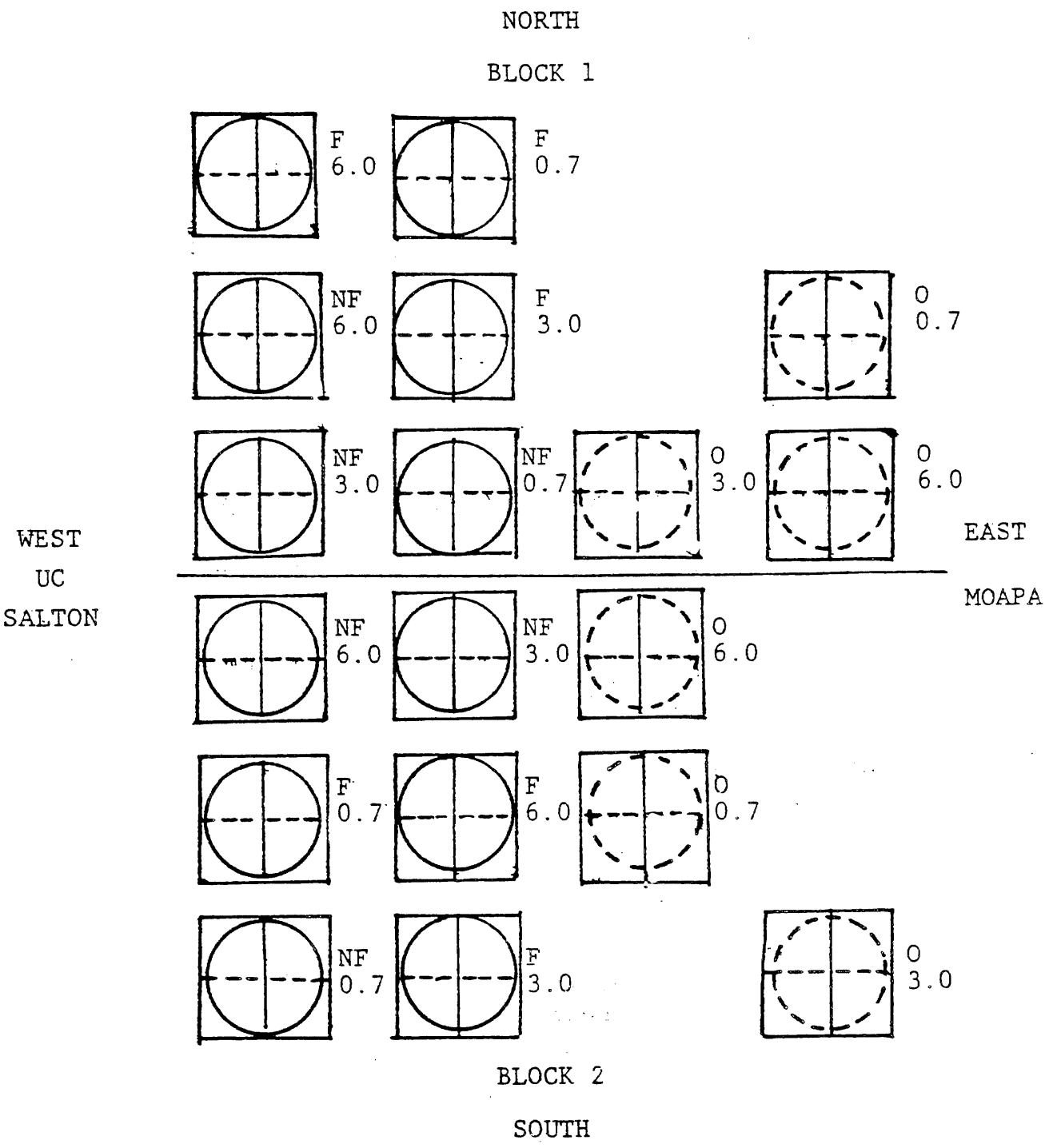

Figure 1. Diagram of plot layout for ozone x salinity study. Eighteen of 24 available salinity plots (squares) were used for the study. Nine plots were used in each of the north and south blocks. Moapa and U.C. Salton, respectively, were planted in the east and west halves of the inside of each circular plot. Mesa Sirsa and Cuff 101, respectively, were planted in the east and west halves outside of each circle. Each plot was further divided into north and south halves to result in location subplots for each cultivar.

plots. The O_3 concentrations were determined with computer software developed at the University of California, Riverside.

The open-top field chambers worked well to modify plot O_3 concentrations. Filtered chambers had O_3 concentrations that were 23% of the outside ambient air averaged over the four exposure harvests (Table 2). Ozone concentrations in ambient air chambers were 90% of those outside for the first three exposure harvests. During the fourth harvest O_3 concentrations in the ambient chambers were increased to approximately 98 $\mu g\ m^{-3}$ above those outside, which resulted in a exposure O_3 average that was 68% higher than outside. The first two harvests had average O_3 concentrations just slightly less than the 198 $\mu g\ m^{-3}$ shown to significantly reduce alfalfa yields during the summer (25). However, O_3 concentrations were much less than normal during the third harvest due to the rainy, overcast weather which was not conducive to O_3 formation in the atmosphere. This low O_3 level likely was inadequate to affect alfalfa growth. O_3 was added to the ambient chambers during the fourth harvest to attempt to obtain a significant O_3 response for determination of the O_3 x salinity interaction on plant growth. The O_3 concentration attained in

Table 2. Ozone Concentrations for Oxidant-Salinity Study at Riverside, California in 1985[a]

Treatment	Exposure Period and Harvest			
	First 7/19-8/12	Second 8/14-9/4	Third 9/6-10/8	Fourth 10/9-11/16
	$\mu g\ m^{-3}$			
Filtered Chamber	39 ± 53	49 ± 62	26 ± 26	18 ± 19
Ambient Chamber	141 ± 57	153 ± 92	110 ± 77	165 ± 119[b]
Outside	157 ± 64	174 ± 106	118 ± 82	98 ± 77

[a]Values are means ± SD of 6, 6, and 2 plots for filtered chambers, ambient chambers, and outside plots, respectively; for 12-hour hourly values between 0800-1959 daily.
[b]Approximately 98 $\mu g\ m^{-3}$ O_3 added daily between 0900-1559.

the ambient chambers was greater than that during the first two harvests. Because the weather conditions were still overcast and humid, this high O_3 concentration should have had an even greater impact on plant growth than did the higher O_3 concentration occurring during the warmer, drier first two harvests.

B. Salinity Treatments

The experimental design included three soil salinity treatments: a low or "control" level representative of nonsaline soils, and medium and high salinity levels representative of soils with salinity problems. The low soil salinity level was achieved by irrigating with normal Riverside tap water with a predicted electrical conductivity (EC) of approximately 0.7 dS m^{-1}. The medium and high salinity levels were achieved by irrigating with tap water to which equal weights of NaCl and $CaCl_2$ were added to obtain water conductivities of approximately 3.0 and 6.0 dS m^{-1}.

Saline treatments were imposed initially by presalinizing the plots prior to planting to obtain a saline soil profile. However, to ensure optimum plant germination and emergence, all plots were then irrigated with 5 cm of non-saline water before planting to provide a non-saline seedbed. After seedlings became established, salinity of the irrigation waters were increased stepwise to their respective salt levels. Prior to planting, triple superphosphate was mixed into the top 0.25 m of soil at the rate of 73 kg P ha^{-1}. To ensure adequate N and K fertility throughout the experiment, 0.6 m molar $Ca(NO_3)_2$ and 1.0 m molar KNO_3 were added in every irrigation.

Each of the three salinity treatments was replicated three times and randomly located within each of two 6-plot-blocks (Figure 1). Actual soil salinity levels were measured once during each of the one pre-exposure and four exposure harvests on 7/22, 8/15, 9/10, 10/9, and 11/22/85. Soil cores were taken from each plot with three subsamples removed from successive depths of 0-0.31, 0.31-0.62, and 0.62-0.93 m. The conductivity of the saturated-soil extracts (EC_e) was measured on a conductivity bridge for each subsample, and the conductivities from the subsamples were averaged to determine the mean salinity over the entire rooting depth in each plot.

Table 3. Mean Electrical Conductivity of Saturated Soil Extracts (EC_e) for Each Air-Soil Salinity Treatment[a]

Sample Date	Air Treatment[b]	EC_e of Irrigation Water (dS m^{-1})		
		0.7	3.0	6.0
		Soil EC_e (dS m^{-1})[a]		
8/15/85	Filtered	1.5 ± 0.7	5.2 ± 0.4	9.0 ± 0.9
	Ambient	1.4 ± 0.6	5.7 ± 0.6	7.8 ± 1.5
	Outside	1.9 ± 0.6	7.0 ± 3.7	12.4 ± 0.1
9/10/85	Filtered	1.7 ± 0.5	6.5 ± 0.7	9.6 ± 0.5
	Ambient	1.5 ± 0.1	6.0 ± 0.9	8.5 ± 0.7
	Outside	1.9 ± 0.2	7.8 ± 1.0	13.1 ± 2.9
10/9/85	Filtered	1.8 ± 1.1	5.5 ± 1.1	7.8 ± 1.9
	Ambient	1.3 ± 0.3	5.1 ± 1.4	7.9 ± 0.3
	Outside	3.0 ± 0.9	8.1 ± 1.9	11.4 ± 0.8
11/22/85	Filtered	1.5 ± 0.8	6.5 ± 0.1	8.1 ± 2.9
	Ambient	1.4 ± 0.1	5.7 ± 1.7	8.3 ± 0.3
	Outside	3.1 ± 0.4	7.6 ± 1.0	11.6 ± 1.0
Mean All Harvests	Filtered	1.6 ± 0.6	5.9 ± 0.8	8.5 ± 1.6
	Ambient	1.4 ± 0.1	5.6 ± 1.0	8.1 ± 0.7
	Outside	2.5 ± 0.7	7.6 ± 1.7	12.1 ± 1.4
	Average	1.8 ± 0.7	6.4 ± 1.5	9.6 ± 2.2

[a]Values are means ± SD for two samples, one from each of two replicate plots.

Table 3 indicates the mean EC_e's for the three salinity treatments for each air quality treatment at four dates, one per exposure period. Mean EC_e's were relatively uniform at all salinity levels for filtered and ambient chamber treatments, but were higher for the outside treatment. Evidently, the salinity was at higher levels in the outside plots due to carry-over of salinity from previous years, despite the fact that the plots were all uniformly drained with non-saline water at the start of the study. The soil salinity level in the medium outside plots was actually similar to the level for high ambient air plots. Thus the plant data from these two treatments was qualitatively (non-statistically) compared to evaluate possible chamber effects on plant response.

The mean all-harvest soil salinity levels attained those of the original experimental design. Based on published salt tolerance data (19), one would expect 0, 26, and 57% yield reductions at the low, medium, and high salinity levels in the filtered and ambient plots. The range of actual soil salinity levels is representative of those that can be found in the field. The mean seasonal soil salinities listed in Table 3 were used to indicate salinity levels for evaluation of experimental results.

C. Plant Culture

Two cultivars of alfalfa (Medicago sativa) were used in this study: Moapa, a moderately O_3 sensitive cultivar that is also relatively sensitive to salinity and U.C. Salton, a salt tolerant line of unknown sensitivity to O_3. Seed was sown (broadcast) on approximately April 15, 1985 in 18, 4.3 x 4.3 m plots. The seeding rate was adequate to produce approximately 400 plants m^{-2}. The plots are enclosed by concrete borders to a depth of 0.75 m and contain Pachappa fine sandy loam. The seed bed was leveled before planting to facilitate flood irrigations.

Each cultivar was planted in separate halves of each plot. Initially, there were approximately 2,900 plants per chamber, 1,450 of each cultivar. This large population allowed for adequate plant mass for the first harvest. As the growing season progressed, natural competition reduced the population in the plots. The area around the perimeter of the circle and 0.31 m in from the edge was not harvested due to possible wall effects on growth. Yield was determined from all plants harvested from each quarter circle (1.12 m^2 quadrant) in the center of the plots.

The plants received regular flood irrigations with either saline or non-saline water approximately weekly to maintain the desired soil, water and salinity levels. Tensiometers were installed at 0.3 and 0.6 m depths in the root zone to monitor soil water conditions. All plots were irrigated when the average soil matric potential reached approximately -50 J/kg at a depth of 0.3 m. Pesticides were applied as needed according to accepted management practices.

D. Physiological Measurements

Physiological changes in plants from the various treatments were evaluated by measuring net photosynthesis, stomatal conductance, water

potential and mineral composition. Measurements were made just before each harvest, usually on the same day. Photosynthesis and stomatal conductance were measured with a dual isotope porometer and a LI-COR® LI 1600 steady state water vapor diffusion porometer, respectively. Plant water potential for stems was measured with a Scholander pressure bomb. There was one measurement per quadrant. Chlorophyll and carotenoid concentrations in leaf tissue were determined by acetone extraction and spectrophotometric measurement (18,29), but only at the fourth harvest.

E. Elemental Analysis

Elemental analysis was performed by the U.S.D.A. Salinity Laboratory on plant samples collected prior to the second exposure harvest on September 5, 1985. Leaf and stem tissues were analyzed together. Concentrations of phosphorous (P) in the tissue were determined colorimetrically (17). Concentrations of chloride (Cl) in the tissue were determined by a coulometric-amperometric procedure (7). Concentrations of calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na), were determined by atomic absorption analysis.

F. Growth, Yield and Injury

There were four harvests during the growing season from July 11, 1985 to November 18, 1985. At harvest, the plants were cut 0.05 m above the soil level and the height, fresh weight, number of nodes per stem, and number of empty nodes per stem were measured. Fresh and dry weights were expressed on a quadrant basis. Height, number of nodes per stem, and number of empty nodes were measured for five stems per quadrant. The plant tops were then oven dried and weighed to determine dry matter yields. The ratio of number of empty nodes to total number of nodes per stem was used to calculate % empty nodes. The ratio of dry to fresh weights was used to calculate % dry matter.

Leaf injury was assessed once, just prior to the 11/85 harvest. The injury was evaluated on a 0-4 scale, with 0 = no chlorosis or necrosis, 1 = 1 to 25% of leaf area injured, 2 = 26 to 50% injured, 3 = 51 to 75% injured, and 4 = 76 to 100% of leaf area injured.

G. Statistical Methods

All physiological, elemental content, growth and yield response parameters were tested statistically by analysis of variance (ANOVA) (30). The analysis of variance used to determine treatment effects and interactions was as shown in Table 4. Additional, less important, interaction terms involving blocks were lumped together to increase the degrees of freedom for Error B. Data for leaf injury (0-4 ratings) was log transformed prior to analysis.

After a preliminary analysis, it was determined that the outside plot data could not be used in conjunction with the analysis of chamber data. Thus the ANOVA model shown in Table 4 is only for filtered and ambient chambers. The higher salinity levels in outside plots made the data incompatible with chamber data from similar low, medium and high salinity plots. However, because the soil salinity level was actually similar for high ambient chamber and medium outside plots, those treatments could be compared qualitatively, but non-statistically to determine any chamber effects on plant response.

Data for chlorophyll and carotenoil content were analyzed with a simple two-way analysis of variance. Filtered and ambient chambers were levels of one factor, and the soil salinity treatments were levels of the second factor. There was one sample per chamber, with the alfalfa cultivar unspecified.

Table 4. Analysis of Variance for Ozone x Salinity Study[a]

Source of Variation	DF
Block	1
Salinity Level	2
Linear	(1)
Residual	(1)
Air	1
Salinity x Air	2
Salinity linear x air	(1)
Salinity residual x air	(1)
Error A	5
Cultivar	1
Direction	1
Cultivar x Direction	1
Cultivar x Salinity	2
Cultivar x Air	1
Cultivar x Salinity x Air	2
Direction x Salinity	2
Direction x Air	1
Direction x Salinity x Air	2
Cultivar x Direction x Salinity	2
Cultivar X Direction x Air	1
Cultivar X Direction x Salinity x Air	2
Error B	18
Total	47

[a]This analysis of variance considers the mean treatment effects due to salinity and air, focusing on contrasts between filtered and nonfiltered chambers. Outside plots were not included. Numbers in parentheses are for comparisons within main treatments. The direction is the north vs. south quadrant for each cultivar within each chamber. Block is the north vs. south set of nine salinity plots.

III. RESULTS AND DISCUSSION

A. Physiology

Physiological measurements indicated few changes in basic plant metabolism that could be attributed to any individual treatment or interaction between treatments (Table 5). This lack of effects appeared to be real as treatment means were often similar for filtered and ambient air treatments. However, it could not be ruled out that this lack of significant effects was primarily an artifact associated with inadequate frequency of measurement or number of replicates per measurement. Results for stomatal conductance are shown in Tables 6 and 7, for leaf water pressure potential in Tables 8 and 9, for net photosynthesis in Tables 10 and 11, and for pigment content in Table 12.

1. Ozone Effects

There were no consistent differences between ambient and filtered chambers that would indicate significant effects from O_3 on physiology. U.C. Salton tended to have lower stomatal conductance in ambient compared to filtered chambers on 11/18/85 (Table 7); lower net photosynthesis for U.C. Salton on 8/9/85 (Table 10); and possibly lower pigment content for alfalfa as a whole on 11/18/85 (Table 12). However none of these differences between chambers were statistically significant, at least in part because of the large variation between replicates as shown by the large standard deviations.

2. Salinity Effects

Salinity by itself only significantly affected alfalfa physiology during the last harvest. Both cultivars tended to have the lowest stomatal conductances at the highest salinity treatment, especially on 11/15 and 11/18/85 (Table 7). However, the salinity effect on even these dates was not statistically significant. Stem water potential was significantly more negative with higher soil salinities on 11/18/85 (Table 9). Plants in the highest salinity treatment tended to have the lowest net photosynthetic rate for U.C. Salton on 8/9/85 (Table 10), and Moapa on 11/15/85 (Table 11). However, the effect was statistically significant only for Moapa on 11/15/85.

Table 5. Summary of ANOVA for Physiological Measurements for Filtered and Ambient Chambers[a]

Treatment	Stomatal Conductance	Pressure Potential	Net Photosynthesis
		8/9/85	
Salinity	NS	NS	NS
Air	NS	NS	NS
Cultivar	NS	NS	NS
Interactions	NS	*[b]	**[c]
		9/5/85	
Salinity	NS	NS	NS
Air	NS	NS	NS
Cultivar	NS	NS	NS
Interaction	NS	*[b]	NS
		10/8/85	
Salinity	NS	NS	NS
Air	NS	NS	NS
Cultivar	NS	NS	NS
Interaction	NS	NS	*[d]
		11/15/85	
Salinity	NS	-	-
Air	NS	-	-
Cultivar	NS	-	-
Interactions	NS	-	-
		11/18/85	
Salinity	NS	*	*
Air	NS	NS	NS
Cultivar	NS	NS	NS
Interaction	NS	NS	*[b]

[a]Symbols * and ** indicate statistically significant differences at $p<0.05$ and 0.01 levels, respectively.
[b]Significant difference for cultivar x salinity x air interaction.
[c]Significant difference for cultivar x air interaction.
[d]Significant difference for salinity x air interaction.

Table 6. Stomatal Conductance for U.C. Salton and Moapa Alfalfa with Oxidant and Salinity Treatments on 8/9/85 and 9/5/85[a]

Air	Soil Salinity (EC_e, dS m^{-1})	8/9/85		9/5/85	
		U.C. Salton	Moapa	U.C. Salton	Moapa
Filtered Chamber	1.6	1.07 ± .31	0.96 ± .24	1.68 ± .25	1.53 ± .31
	5.9	0.72 ± .63	0.92 ± .51	1.67 ± .06	1.43 ± .25
	8.5	0.72 ± .44	1.01 ± .05	1.70 ± .40	1.56 ± .25
Ambient Chamber	1.4	0.90 ± .37	1.03 ± .25	1.81 ± .25	1.66 ± .19
	5.6	1.19 ± .21	1.10 ± .44	1.34 ± .35	1.76 ± .34
	8.1	0.76 ± .43	0.87 ± .09	1.72 ± .16	1.43 ± .19
Outside	2.5	0.85 ± .20	0.75 ± .35	-[b]	-[b]
	7.6	0.96 ± .18	1.21 ± .11	-	-
	12.1	1.03 ± .32	1.03 ± .08	-	-

[a]Values are means ± SD for four observations, two from each of two replicate plots.
[b]Not measured because of rain.

Table 7. Stomatal Conductance for U.C. Salton and Moapa Alfalfa with Oxidant and Salinity Treatments on 10/8/85, 11/15/85, and 11/18/85[a]

Air	Soil Salinity (EC_e, dS m^{-1})	10/8/85		11/15/85		11/18/85	
		U.C. Salton	Moapa	U.C. Salton	Moapa U.S.	Salton	Moapa
		cm s^{-1}					
Filtered Chamber	1.6	1.09 ± 0.52	1.10 ± 0.12	0.35 ± 0.11	0.23 ± 0.08	0.79 ± 0.17	0.87 ± 0.25
	5.9	0.90 ± 0.10	0.93 ± 0.31	0.24 ± 0.14	0.33 ± 0.16	0.70 ± 0.16	0.69 ± 0.23
	8.6	1.07 ± 0.39	0.92 ± 0.25	0.20 ± 0.07	0.31 ± 0.17	0.67 ± 0.31	0.48 ± 0.15
Ambient Chamber	1.4	0.78 ± 0.34	0.99 ± 0.40	0.29 ± 0.11	0.45 ± 0.21	0.68 ± 0.27	0.66 ± 0.33
	5.6	0.87 ± 0.45	0.92 ± 0.12	0.32 ± 0.13	0.37 ± 0.23	0.70 ± 0.06	0.46 ± 0.32
	8.1	0.97 ± 0.26	0.80 ± 0.36	0.14 ± 0.03	0.23 ± 0.15	0.59 ± 0.16	0.53 ± 0.16
Outside	2.5	1.19 ± 0.20	1.43 ± 0.22	0.52 ± 0.21	0.47 ± 0.36	1.09 ± 0.06	1.00 ± 0.11
	7.6	0.97 ± 0.16	1.13 ± 0.20	0.45 ± 0.24	0.62 ± 0.15	0.86 ± 0.26	1.02 ± 0.17
	12.1	0.62 ± 0.40	1.08 ± 0.48	0.31 ± 0.12	0.36 ± 0.10	0.68 ± 0.32	0.78 ± 0.29

[a]Values are means ± SD for four observations, two from each of two replicate plots.

Table 8. Pressure Potential for U.C. Salton and Moapa Alfalfa Stems with Oxidant and Salinity Treatments on 8/9/85 and 9/5/85[a]

Air	Soil Salinity (EC_e, dS m^{-1})	8/9/85		9/5/85	
		U.C. Salton	Moapa	U.C. Salton	Moapa
		MPa			
Filtered	1.6	-1.5 ± .2	-0.8 ± .8	-0.7 ± .4	-0.7 ± .3
Chamber	5.9	-2.2 ± .1	-1.6 ± .5	-0.7 ± .4	-1.2 ± .6
	8.6	-1.6 ± .4	-1.9 ± .2	-1.2 ± .2	-0.8 ± .4
Ambient	1.4	-1.2 ± .1	-1.1 ± .3	-0.9 ± .5	-1.0 ± .4
Chamber	5.6	-1.4 ± .6	-1.4 ± 1.1	-1.0 ± .5	-0.6 ± .3
	8.1	-1.9 ± .1	-1.4 ± .9	-0.6 ± .3	-0.3 ± .1
Outside	2.5	-1.1 ± .4	-0.9 ± .8	_[b]	_[b]
	7.6	-1.9 ± .6	-1.4 ± .5	-	-
	12.1	-1.5 ± .7	-1.4 ± .7	-	-

[a]Values are means ± SD for four observations, two from each of two replicate plots.
[b]Not measured because of rain.

Table 9. Pressure Potential for U.C. Salton and Moapa Alfalfa with Oxidant and Salinity Treatments on 10/8/85 and 11/18/85[a]

Air	Soil Salinity (EC_e, dS m^{-1})	10/8/85		11/18/85	
		U.C. Salton	Moapa	U.C. Salton	Moapa
			MPa		
Filtered chamber	1.6	-1.3 ± 0.3	-1.3 ± 0.1	-1.7 ± 0.3	-1.6 ± 0.4
	5.9	-1.6 ± 0.7	-1.6 ± 1.0	-2.0 ± 0.3	-2.1 ± 0.2
	8.6	-1.9 ± 0.6	-1.3 ± 0.7	-1.7 ± 0.8	-2.0 ± 0.4
Ambient chamber	1.4	-1.2 ± 0.7	-1.2 ± 0.4	-1.7 ± 0.2	-1.3 ± 0.3
	5.6	-1.7 ± 0.9	-1.3 ± 0.5	-1.9 ± 0.1	-1.8 ± 0.3
	8.1	-0.9 ± 0.6	-1.0 ± 0.6	-2.0 ± 0.6	-2.0 ± 0.5
Outside	2.5	-1.4 ± 0.4	-1.3 ± 0.4	-1.6 ± 0.1	-1.7 ± 0.1
	7.6	-1.1 ± 0.8	-1.7 ± 0.7	-1.9 ± 0.4	-1.6 ± 0.3
	12.1	-2.2 ± 0.7	-1.8 ± 0.3	-2.0 ± 0.4	-2.0 ± 0.2

[a]Values are means ±SD for four observations, two from each of two replicate plots.

Table 10. Net Photosynthesis for U.C. Salton and Moapa Alfalfa with Oxidant and Salinity Treatments on 8/9/85 and 9/5/85[a]

Air	Soil Salinity (EC_e, dS m^{-1})	8/9/85		9/5/85	
		U.C. Salton	Moapa	U.C. Salton	Moapa
			μmol m^{-2} s^{-1}		
Filtered	1.6	16.3 ± 8.4[b]	10.4 ± 1.5[b]	6.4 ± 3.3	7.2 ± 4.5
Chamber	5.9	12.8 ± 2.6	7.1 ± 1.3	8.4 ± 2.1	8.0 ± 1.2
	8.6	9.5 ± 5.3	8.2 ± 1.5	6.6 ± 1.6	7.1 ± 2.8
Ambient	1.4	6.8 ± 6.2	6.7 ± 4.9	6.8 ± 2.0	7.1 ± 2.4
Chamber	5.6	12.7 ± 3.9	9.9 ± 2.9	7.9 ± 1.6	10.8 ± 2.3
	8.1	5.5 ± 1.4	10.1 ± 5.5	8.3 ± 2.1	9.0 ± 3.5
Outside	2.5	13.7 ± 6.8	20.6 ± 4.3	-[c]	-[c]
	7.6	16.5 ± 10.1	19.7 ± 5.9	-	-
	12.1	22.9 ± 5.5	17.4 ± 2.4	-	-

[a]Values are means ± SD for four observations, two from each replicate plots.
[b]Two observations from one replicate.
[c]Not measured because of rain.

Table 11. Net Photosynthesis for U.C. Salton and Moapa Alfalfa with Oxidant and Salinity Treatments on 10/8/85 and 11/18/85[a]

Air	Soil Salinity (EC_e, dS m^{-1})	10/8/85		11/18/85	
		U.C. Salton	Moapa	U. C. Salton	Moapa
		μmol m^{-2} s^{-1}			
Filtered Chamber	1.6	21.78 ± 5.44	19.80 ± 2.42	22.89 ± 8.64	23.42 ± 17.50
	5.9	21.02 ± 3.10	24.75 ± 4.34	20.26 ± 7.39	18.85 ± 3.85
	8.6	32.69 ± 15.21	20.25 ± 3.96	21.62 ± 14.15	27.60 ± 18.86
Ambient Chamber[b]	1.4	29.51 ± 8.37	23.27 ± 14.93	28.94 ± 10.62	18.17 ± 9.80
	5.6	24.49 ± 7.34	20.93 ± 3.97	18.65 ± 6.34	30.54 ± 5.01
	8.1	15.46 ± 7.55	16.97 ± 4.39	10.89 ± 4.46	14.89 ± 4.75
Outside	2.5	25.50 ± 6.35	26.79 ± 10.73	12.84 ± 1.72	12.51 ± 4.46
	7.6	20.67 ± 7.08	30.94 ± 2.10	20.23 ± 7.16	30.41 ± 7.07
	12.1	15.18 ± 6.94	16.59 ± 8.40	24.47 ± 8.72	30.23 ± 4.56

[a]Values are means ± SD for four observations, two from each of two replicate plots.
[b]Ambient chambers received an added 98 μg m^{-3} of O_3 between 0900 and 1600 daily for the 11/15/85 harvest.

Table 12. Total Chlorophyll and Carotenoid Concentrations, and Chlorophyll a/b Ratio for Alfalfa Plants Exposed to Ozone at Different Salinity Treatments on 11/18/85[a]

Air	Soil Salinity (EC_e,d S^{-1})	Total Chlorophyll ($\mu g\ ml^{-1}$)	Chlorophyll Ratio (a/b)	Total Carotenoids ($\mu g\ ml^{-1}$)
Filtered	1.6	367 ± 47	3.33 ± 0.01	78.0 ± 1.6
Chamber	5.9	465 ± 98	3.09 ± 0.20	101.6 ± 27.8
	8.6	241 ± 33	3.44 ± 0.02	60.3 ± 12.8
Ambient[b]	1.4	219 ± 51	7.55 ± 6.11	69.0 ± 14.0
+ Ozone	5.6	169 ± 55	5.19 ± 3.03	58.6 ± 27.8
Chamber	8.1	287 ± 21	3.24 ± 0.52	70.8 ± 5.9
Outside	2.5	248 ± 212	3.67 ± 0.04	90.7 ± 2.6
	7.6[b]	---	---	---
	12.1[b]	---	---	---

[a]Values are means ± SD of two observations, one from each replicate chamber and outside plot. There was one pooled 0.200 fresh weight sample per chamber or outside plot. There was a statistically significant difference between filtered and ambient + ozone chambers and for air vs. salinity for total chlorophyll at $p<0.05$.
[b]Not sampled.

3. Cultivar Effects

There were no differences in physiological responses between cultivars across both air treatments and salinity.

4. Chamber Effects

The chamber itself seemed to modify alfalfa physiology, especially toward the end of the growing season. Stomatal conductance tended to be higher in medium salinity outside plots compared to high salinity ambient chambers on 10/8, 11/15, and 11/18/85 (Table 7); but no statistical comparisons could be made. Net photosynthesis tended to be higher in outside compared to ambient chambers on 8/9/85 (Table 10). The chamber environment tended to have a warmer temperature, but lower light intensity compared to outside plots as the growing season progressed. This caused etiolation of chamber compared to outside plants, resulting in stem collapse or 'lodging'. The lodging caused greater shading of leaves which may have encouraged the lower net photosynthesis rates and hence lower stomatal conductance rates in chambers.

5. Interactions

There were statistically significant interactions between major treatment factors for water potential and photosynthesis. Apparently the highest photosynthetic rate was for Moapa, with increasing salinity, in outside plots (Table 11). In contrast, the lowest photosynthetic rate tended to occur for U.C. Salton, with increasing salinity, in ambient chamber plots.

B. Elemental Analysis

Concentrations of different elements either increased, decreased, or stayed the same depending on treatment and treatment interactions. The results from the statistical analysis are shown in Table 13. The treatment data are shown in Table 14.

1. Ozone Effects

Ozone did not have any effect on leaf elemental content except for a higher Ca concentration in filtered compared to ambient chambers (Table 14).

Table 13. Summary of Elemental Content Statistical Analysis for 9/5/85 Harvest[a]

Treatment	Element					
	P	K	Ca	Mg	Na	Cl
Salinity	**	NS	NS	*	*	***
Air	NS	NS	**	NS	NS	NS
Cultivar	NS	**	***	NS	***	NS
Interaction	*[b]	NS	NS	NS	NS	NS

[a]Symbols *, **, and *** indicate statistically significant differences at $p<0.05$, 0.01 and 0.005 levels, respectively.
[b]Significant cultivar x salinity x air interaction.

Table 14. Elemental Content for Alfalfa Harvested on 9/5/85

Air	Soil Salinity (EC_e, dS m^{-1})	Element Concentration (mmol kg^{-1} dry weight)[a]					
		P	K	Ca	Mg	Na	Cl
				U.C. Salton			
Filtered Chamber	1.6	103 ± 6	1248 ± 86	366 ± 9	99 ± 1	54 ± 12	263 ± 43
	5.9	97 ± 4	1186 ± 36	351 ± 17	74 ± 3	70 ± 16	558 ± 8
	8.6	89 ± 4	1190 ± 34	361 ± 12	70 ± 3	91 ± 11	635 ± 41
Ambient Chamber	1.4	107 ± 2	1286 ± 100	307 ± 8	83 ± 9	41 ± 4	227 ± 70
	5.6	90 ± 12	1227 ± 33	324 ± 17	73 ± 1	72 ± 12	555 ± 5
	8.1	93 ± 4	1212 ± 46	349 ± 16	76 ± 8	88 ± 8	642 ± 27
Outside	2.5	92 ± 15	898 ± 67	307 ± 9	103 ± 3	109 ± 12	199 ± 16
	7.6	83 ± 7	874 ± 65	328 ± 11	86 ± 2	110 ± 7	472 ± 26
	12.1	80 ± 6	867 ± 17	353 ± 7	77 ± 3	98 ± 8	547 ± 18
				Moapa			
Filtered Chamber	1.4	100 ± 3	1271 ± 18	353 ± 14	97 ± 5	37 ± 12	279 ± 47
	5.9	93 ± 4	1283 ± 90	350 ± 24	79 ± 4	54 ± 10	575 ± 16
	8.6	91 ± 8	1215 ± 74	358 ± 14	70 ± 3	62 ± 17	633 ± 76
Ambient Chamber	1.4	99 ± 4	1261 ± 17	306 ± 6	79 ± 5	28 ± 3	211 ± 62
	5.6	101 ± 4	1310 ± 39	313 ± 19	72 ± 3	51 ± 5	550 ± 23
	8.1	92 ± 7	1284 ± 55	346 ± 23	76 ± 10	61 ± 4	648 ± 29
Outside	2.5	98 ± 8	927 ± 26	297 ± 5	103 ± 2	76 ± 4	241 ± 35
	7.6	93 ± 4	904 ± 108	305 ± 5	88 ± 3	73 ± 8	455 ± 25
	12.1	87 ± 1	896 ± 50	326 ± 23	67 ± 3	62 ± 5	514 ± 31

[a]Values are means ± SD for four observations, two from each of two replicate plots.

2. Salinity Effects

The concentrations of P and Mg were lower and Na and Cl higher with increasing salinity levels (Table 14).

3. Cultivar Effects

Concentrations of K and Ca were lower and Na higher in U.C. Salton than Moapa on (Table 14).

4. Chamber Effects

Concentrations of K and Cl tended to be lower, and Na higher in outside compared to chamber plots on (Table 14).

5. Interactions

The only significant interaction was a cultivar x salinity x air interaction for P (Table 14). Concentrations of P decreased with increasing salinity, but especially for U.C. Salton in ambient chambers.

C. Growth, Yield and Injury

All three major treatment factors: air, salinity, and cultivar had statistically significant effects on alfalfa growth and yield (Table 15). There also were a number of different combinations of interactions for different parameters at different harvests. Results for the 8/12, 9/5, 10/9, and 11/18 harvests are shown in Tables 16, 17, 18, and 19, respectively. Total season fresh and dry weight, and stand count data are shown in Table 20, and leaf injury data in Table 21.

1. Ozone Effects

The primary statistically significant O_3 effects concerned leaf loss. Percent empty nodes, an indicator of premature leaf senescence, was significantly greater on plants grown in ambient than in filtered chambers for the 8/12, 9/5, and 11/18/85 harvests (Table 15). Leaf injury rated just prior to the 11/18/85 harvest, also was greater for plants in ambient than in filtered chambers (Table 21).

There were few other significant differences between ambient and filtered chambers for any parameter or harvest. There was a slight trend toward lower fresh and dry weights for ambient vs. filtered chambers at the 8/12 and 9/5/85 harvests (Tables 16 and 17). However, the small number of replicates and the large variation between them made this difference difficult to detect except for fresh weight on 8/12/86. The greater height for ambient vs. filtered chambers at the 10/9 harvest can

Table 15. Summary of Growth and Yield Statistical Analysis[a]

Treatment	Total Fresh Weight	Total Dry Weight	% Dry Weight	Height	% Empty Nodes
			8/12/85		
Salinity	**	*	**	NS	NS
Air	*	NS	NS	NS	**
Cultivar	***	*	NS	***	NS
Interaction	*[d,e]	NS	NS	NS	NS
			9/5/85		
Salinity	NS	*	NS	NS	*
Air	NS	**	NS	NS	**
Cultivar	**	***	NS	NS	*
Interaction	NS	NS	*[c]	NS	*[b,d]
			10/9/85		
Salinity	*	NS	**	**	*
Air	NS	NS	NS	*	NS
Cultivar	*	***	*	*	NS
Interaction	NS	NS	NS	NS	NS
			11/18/85		
Salinity	NS	NS	NS	*	NS
Air	NS	NS	NS	NS	**
Cultivar	***	***	NS	*	NS
Interaction	*[d]	NS	NS	NS	NS

[a]Symbols *, **, and *** indicate statistically significant differences at $p<0.05$, 0.01, and 0.005 levels, respectively.
[b]Significant salinity x air interaction.
[c]Significant cultivar x salinity interaction.
[d]Significant cultivar x air interaction.
[e]Significant cultivar x salinity x air interaction.

Table 16. Growth and Yield of U.C. Salton and Moapa Alfalfa Harvested on 8/12/85 After Oxidant and Salinity Treatments[a]

Air	Soil Salinity (EC_e, dS m^{-1})	Total Fresh Weight (kg m^{-1})	Total Dry Weight (kg m^{-1})	% Dry Weight	Height (m)	% Empty Nodes
			U.C. Salton			
Filtered Chamber	1.6	1.89 ± 0.47	0.37 ± 0.06	20 ± 2	0.59 ± 0.13	42 ± 16
	5.9	1.61 ± 0.15	0.37 ± 0.04	23 ± 1	0.49 ± 0.03	35 ± 9
	8.6	1.45 ± 0.20	0.34 ± 0.05	23 ± 1	0.45 ± 0.05	33 ± 15
Ambient Chamber	1.4	1.79 ± 0.10	0.36 ± 0.02	20 ± 0	0.64 ± 0.14	65 ± 17
	5.6	1.52 ± 0.03	0.36 ± 0.02	23 ± 1	0.52 ± 0.05	49 ± 12
	8.1	1.39 ± 0.09	0.34 ± 0.02	25 ± 1	0.49 ± 0.05	50 ± 15
Outside	2.5	2.03 ± 0.13	0.37 ± 0.05	20 ± 2	0.64 ± 0.07	57 ± 9
	7.6	1.54 ± 0.17	0.36 ± 0.05	23 ± 1	0.52 ± 0.10	57 ± 16
	12.1	1.04 ± 0.43	0.28 ± 0.10	27 ± 2	0.39 ± 0.08	52 ± 11
			Moapa			
Filtered Chamber	1.6	2.03 ± 0.26	0.37 ± 0.05	19 ± 1	0.56 ± 0.11	40 ± 11
	5.9	1.43 ± 0.04	0.33 ± 0.01	23 ± 2	0.46 ± 0.03	40 ± 8
	8.6	1.34 ± 0.05	0.32 ± 0.01	24 ± 1	0.43 ± 0.04	39 ± 10
Ambient Chamber	1.4	1.47 ± 0.14	0.32 ± 0.04	22 ± 1	0.58 ± 0.11	74 ± 15
	5.6	1.33 ± 0.24	0.32 ± 0.05	25 ± 1	0.51 ± 0.04	54 ± 9
	8.1	1.21 ± 0.09	0.30 ± 0.02	25 ± 2	0.48 ± 0.09	51 ± 18
Outside	2.5	1.69 ± 0.07	0.39 ± 0.04	23 ± 1	0.53 ± 0.04	60 ± 12
	7.6	1.38 ± 0.17	0.33 ± 0.05	24 ± 2	0.46 ± 0.05	44 ± 12
	12.1	1.01 ± 0.53	0.26 ± 0.12	26 ± 4	0.39 ± 0.10	46 ± 17

[a]Values are means for four (total fresh weight, total dry weight, % dry weight) or 10 (height, % empty nodes) observations ± SD, two or five from each of two blocked plots.

Table 17. Growth and Yield of U.C. Salton and Moapa Alfalfa Harvested on 9/5/85 after Oxidant and Salinity Treatments[a]

Air	Soil Salinity (EC_e, dS m^{-1})	Total Fresh Weight (kg m^{-1})	Total Dry Weight (kg m^{-1})	% Dry Weight	Height (m)	% Empty Nodes
			U.C. Salton			
Filtered Chamber	1.6	2.22 ± 0.29	0.30 ± 0.04	14 ± 1	0.66 ± 0.10	24 ± 15
	5.9	2.05 ± 0.21	0.34 ± 0.01	17 ± 1	0.57 ± 0.06	25 ± 7
	8.6	1.83 ± 0.24	0.30 ± 0.04	17 ± 1	0.53 ± 0.05	23 ± 7
Ambient Chamber	1.4	1.72 ± 0.21	0.27 ± 0.02	16 ± 1	0.60 ± 0.12	71 ± 13
	5.6	1.83 ± 0.17	0.29 ± 0.01	16 ± 1	0.59 ± 0.06	43 ± 12
	8.1	1.83 ± 0.02	0.29 ± 0.02	16 ± 1	0.56 ± 0.07	35 ± 13
Outside	2.5	1.69 ± 0.18	0.31 ± 0.05	18 ± 1	0.49 ± 0.03	72 ± 14
	7.6	1.77 ± 0.09	0.30 ± 0.02	18 ± 1	0.49 ± 0.04	43 ± 8
	12.1	1.27 ± 0.21	0.27 ± 0.05	21 ± 0	0.38 ± 0.06	42 ± 13
			Moapa			
Filtered Chamber	1.6	1.81 ± 0.24	0.28 ± 0.03	15 ± 1	0.61 ± 0.10	36 ± 13
	5.9	1.77 ± 0.19	0.28 ± 0.03	16 ± 2	0.55 ± 0.07	29 ± 9
	8.6	1.73 ± 0.21	0.27 ± 0.03	16 ± 1	0.57 ± 0.04	37 ± 15
Ambient Chamber	1.4	1.36 ± 0.24	0.22 ± 0.04	16 ± 0	0.56 ± 0.07	63 ± 15
	5.6	1.76 ± 0.12	0.27 ± 0.03	15 ± 1	0.55 ± 0.05	43 ± 12
	8.1	1.83 ± 0.24	0.28 ± 0.04	15 ± 2	0.64 ± 0.14	43 ± 14
Outside	2.5	1.70 ± 0.09	0.31 ± 0.05	18 ± 2	0.47 ± 0.05	55 ± 12
	7.6	1.60 ± 0.12	0.30 ± 0.01	19 ± 2	0.41 ± 0.05	42 ± 11
	12.1	1.10 ± 0.37	0.23 ± 0.07	22 ± 1	0.36 ± 0.07	43 ± 9

[a]Values are for four (total fresh weight, total dry weight, % dry weight) or 10 (height, % empty nodes) observations ± SD; two or five from each of two blocked plots.

Table 18. Growth and Yield of U.C. Salton and Moapa Alfalfa Harvested on 10/9/85 after Oxidant and Salinity Treatments[a]

Air	Soil Salinity (EC_e, dS m^{-1})	Total Fresh Weight (kg m^{-1})	Total Dry Weight (kg m^{-1})	% Dry Weight	Height (m)	% Empty Nodes
			U.C. Salton			
Filtered Chamber	1.6	1.29 ± 0.22	0.21 ± 0.02	17 ± 3	0.63 ± 0.13	37 ± 12
	5.9	1.03 ± 0.14	0.22 ± 0.03	22 ± 1	0.54 ± 0.05	31 ± 11
	8.6	0.98 ± 0.21	0.21 ± 0.03	21 ± 3	0.52 ± 0.09	19 ± 9
Ambient Chamber	1.4	1.05 ± 0.44	0.22 ± 0.01	17 ± 1	0.76 ± 0.09	51 ± 14
	5.4	1.34 ± 0.11	0.22 ± 0.03	19 ± 1	0.59 ± 0.07	33 ± 11
	7.5	1.18 ± 0.14	0.22 ± 0.02	21 ± 2	0.59 ± 0.06	28 ± 10
Outside	2.8	1.73 ± 0.17	0.29 ± 0.03	17 ± 1	0.64 ± 0.07	63 ± 17
	7.5	1.52 ± 0.13	0.27 ± 0.03	18 ± 1	0.61 ± 0.04	39 ± 12
	12.2	1.05 ± 0.44	0.22 ± 0.01	23 ± 4	0.44 ± 0.08	25 ± 11
			Moapa			
Filtered Chamber	1.6	0.94 ± 0.13	0.16 ± 0.04	17 ± 1	0.60 ± 0.08	42 ± 10
	5.8	1.00 ± 0.19	0.20 ± 0.02	20 ± 2	0.55 ± 0.10	31 ± 13
	8.1	0.99 ± 0.24	0.21 ± 0.04	21 ± 2	0.52 ± 0.06	26 ± 7
Ambient Chamber	1.4	1.27 ± 0.07	0.21 ± 0.01	16 ± 1	0.71 ± 0.13	55 ± 17
	5.4	1.08 ± 0.11	0.20 ± 0.03	18 ± 1	0.58 ± 0.09	35 ± 12
	7.5	0.95 ± 0.13	0.21 ± 0.02	21 ± 2	0.53 ± 0.04	30 ± 9
Outside	2.8	1.70 ± 0.11	0.26 ± 0.03	15 ± 2	0.61 ± 0.07	39 ± 12
	7.5	1.43 ± 0.34	0.25 ± 0.06	18 ± 1	0.51 ± 0.10	31 ± 6
	12.2	1.18 ± 0.58	0.21 ± 0.03	22 ± 3	0.45 ± 0.11	27 ± 12

[a]Values are for four (total fresh weight, total dry weight, % dry weight) or 10 (height, % empty nodes) observations ± SD, two or five from each of two blocked plots.

Table 19. Growth and Yield of U.C. Salton and Moapa Alfalfa Harvested on 11/18/85 after Oxidant and Salinity Treatments[a]

Air	Soil Salinity (EC_e, dS m^{-1})	Total Fresh Weight (kg m^{-1})	Total Dry Weight (kg m^{-1})	% Dry Weight	Height (m)	% Empty Nodes
			U.C. Salton			
Filtered Chamber	1.6	0.80 ± 0.24	0.15 ± 0.04	19 ± 2	0.58 ± 0.09	53 ± 17
	5.9	0.67 ± 0.13	0.14 ± 0.03	22 ± 2	0.45 ± 0.07	42 ± 14
	8.6	0.55 ± 0.22	0.12 ± 0.05	22 ± 2	0.39 ± 0.08	44 ± 18
Ambient + Ozone Chamber	1.4	0.54 ± 0.16	0.12 ± 0.03	21 ± 3	0.55 ± 0.09	59 ± 28
	5.6	0.34 ± 0.09	0.08 ± 0.02	22 ± 1	0.47 ± 0.07	46 ± 35
	8.1	0.50 ± 0.64	0.11 ± 0.04	22 ± 2	0.44 ± 0.05	74 ± 17
Outside	2.5	1.10 ± 0.18	0.19 ± 0.03	17 ± 1	0.53 ± 0.07	52 ± 11
	7.6	0.81 ± 0.13	0.15 ± 0.03	19 ± 0	0.46 ± 0.04	59 ± 26
	12.1	0.60 ± 0.25	0.13 ± 0.05	21 ± 2	0.35 ± 0.08	52 ± 20
			Moapa			
Filtered Chamber	1.6	0.50 ± 0.25	0.10 ± 0.05	20 ± 3	0.49 ± 0.13	57 ± 19
	5.9	0.41 ± 0.11	0.09 ± 0.02	21 ± 1	0.46 ± 0.09	43 ± 13
	8.6	0.35 ± 0.09	0.08 ± 0.02	24 ± 2	0.32 ± 0.04	44 ± 15
Ambient + Ozone Chamber	1.4	0.41 ± 0.12	0.08 ± 0.03	21 ± 2	0.52 ± 0.09	89 ± 9
	5.6	0.18 ± 0.12	0.05 ± 0.03	24 ± 1	0.45 ± 0.06	64 ± 34
	8.1	0.41 ± 0.08	0.09 ± 0.02	21 ± 1	0.43 ± 0.04	68 ± 17
Outside	2.5	1.00 ± 0.13	0.17 ± 0.01	17 ± 1	0.47 ± 0.06	45 ± 15
	7.6	0.57 ± 0.13	0.12 ± 0.04	20 ± 1	0.39 ± 0.08	48 ± 13
	12.1	0.52 ± 0.25	0.11 ± 0.05	21 ± 3	0.31 ± 0.09	43 ± 13

[a]Values are for four (total fresh weight, total dry weight, % dry weight) or 10 (height, % empty nodes) observations ± SD, two or five from each of two blocked plots.

Table 20. Total Season Yield, Final Stand Count, and Yield/Stand for U.C. Salton and Moapa Alfalfa after Oxidant and Salinity Treatments[a]

Air	Soil Salinity (EC_e, dS m^{-1})	Total Season Yield[b] Fresh Weight (kg m^{-1})	Total Season Yield[b] Dry Weight (kg m^{-1})	Stand (plants m^{-1})	Yield/Stand[c] (g $plant^{-1}$)
			U.C. Salton		
Filtered Chamber	1.6	6.36 ± 0.54	1.04 ± 0.11	112 ± 37	9.9 ± 2.5
	5.9	5.56 ± 0.46	1.09 ± 0.10	148 ± 15	7.4 ± 1.2
	8.6	3.94 ± 1.31	0.96 ± 0.24	145 ± 12	6.7 ± 1.3
Ambient Chamber	1.4	5.37 ± 0.33	0.95 ± 0.06	125 ± 7	7.6 ± 0.7
	5.6	4.85 ± 0.36	0.95 ± 0.05	156 ± 17	6.1 ± 0.6
	8.1	4.76 ± 0.25	0.96 ± 0.05	173 ± 38	5.8 ± 1.2
Outside	2.5	6.19 ± 0.71	1.20 ± 0.08	190 ± 25	6.4 ± 1.0
	7.6	5.36 ± 0.60	1.09 ± 0.11	109 ± 9	5.7 ± 0.8
	12.1	4.80 ± 0.87	0.88 ± 0.24	103 ± 13	4.9 ± 1.3
			Moapa		
Filtered Chamber	1.6	6.08 ± 0.25	0.93 ± 0.11	139 ± 47	7.2 ± 2.2
	5.9	4.96 ± 0.47	0.88 ± 0.05	114 ± 48	9.8 ± 6.3
	8.6	3.59 ± 1.72	0.88 ± 0.06	148 ± 7	6.0 ± 0.2
Ambient Chamber	1.4	4.49 ± 0.33	0.82 ± 0.06	122 ± 33	7.3 ± 2.5
	5.6	4.33 ± 0.46	0.82 ± 0.10	123 ± 13	6.7 ± 0.4
	8.1	4.17 ± 0.17	0.85 ± 0.06	141 ± 23	6.2 ± 1.0
Outside	2.5	5.47 ± 0.58	1.13 ± 0.08	204 ± 26	5.7 ± 1.3
	7.6	4.60 ± 0.33	1.01 ± 0.08	111 ± 26	5.5 ± 1.2
	12.1	4.40 ± 0.52	0.80 ± 0.32	105 ± 19	4.2 ± 1.3

[a]Values are for four observations ± SD, two from each of two blocked plots. The following single factor effects were statistically significant at $p<0.05$ for filtered and ambient chambers according to the ANOVA: salinity for total fresh weight, cultivar for total fresh and dry weights and yield/stand.
[b]Four exposure harvests.
[c]Yield as dry weight.

Table 21. Leaf Injury (0-4 Rating) for Alfalfa at November Harvest with Oxidant and Salinity Treatments[a]

Air	Soil Salinity (EC_e, dS m^{-1})	Alfalfa Cultivars (Injury Ratings)[b]	
		U.C. Salton	Moapa
Filtered Chamber	1.6	0.8 ± 0.5	1.3 ± 0.5
	5.9	1.0 ± 0.0	1.5 ± 0.6
	8.6	1.5 ± 0.6	1.8 ± 0.5
Ambient + Ozone Chamber	1.4	4.0 ± 0.0	4.0 ± 0.0
	5.6	4.0 ± 0.0	4.0 ± 0.0
	8.1	2.8 ± 1.0	3.3 ± 0.5
Outside	2.5	2.0 ± 0.0	2.0 ± 0.0
	7.6	1.5 ± 0.6	1.3 ± 0.5
	12.1	0.3 ± 0.5	0.5 ± 0.6

[a]Values are means ± SD for four observations, two from each of two replicate plots. There were statistically significant differences between filtered and ambient chambers across salinity levels, between U.C. Salton and Moapa, and salinity x air interaction at $p<0.05$. Outside plot data were not included in the analysis.

[b]The rating scale is 0 = no injury, 1 = 25% of plant area chlorotic and necrotic injury, 2 = 50% injury, 3 = 75%, 4 = 100%. Individual plant data were converted to corresponding percentages and then arcsine transformed prior to statistical analysis.

probably be attributed to the lodging of alfalfa stems in the chambers (Table 19). This resulted in an overall reduction in height in both filtered chambers that was greater than any potential reduction in growth due to O_3. Furthermore lodging of the alfalfa may have decreased gas dispersion within the alfalfa canopy, decreasing the distribution of O_3 to the plants. The O_3 concentration may have been too low in the ambient chamber during late September and early October to affect plant growth prior to the 10/9/85 harvest (Table 2). The added O_3 prior to the 11/18/85 harvest should have had an adverse effect on the alfalfa. However, the general slow growth due to cooler, overcast weather likely decreased the sensitivity of the plants to O_3 during this period.

2. Salinity Effects

Salinity significantly affected many alfalfa growth and yield parameters for all individual harvests (Table 15), and over all four harvests (Table 20). Total fresh and dry weight decreased; while % dry weight increased with increasing salinity on 8/12/85 (Table 18). Total dry weight and percent empty nodes decreased with increasing salinity on 9/5/85 (Table 17). Total fresh weight, height, and % empty nodes decreased, and % dry weight increased with increasing salinity on 10/9/85 (Table 18). Height was decreased with increasing salinity on 11/18/85 (Table 19). Salinity produced a decrease in total season fresh weight, but had no overall effect on stand count of either cultivar (Table 20).

Salinity decreased leaf injury in ambient plus O_3 and outside plots on 11/18/85 (Table 21). The decrease in injury occurred only at the high salt treatment and not the medium as compared to the low control treatment.

3. Cultivar Effects

There were large differences in growth between U.C. Salton and Moapa (Table 15). U.C. Salton had greater total fresh weight, dry weight, and height than Moapa on 8/12/85 (Table 16). U.C. Salton had greater total fresh and dry weight and lower % empty nodes than Moapa on 9/5/85 (Table 17). U.C. Salton had greater total fresh and dry weights, and height compared to Moapa on 10/9/85 and 11/18/85 (Tables 18,19). U.C. Salton also had greater % dry weight than Moapa on 11/18/85 (Table 19),

and greater total seasonal fresh and dry weights and yield/stand than Moapa (Table 20).

The difference in growth between the two cultivars was greatest at the medium and high salinity level as expected due to U.C. Salton's salinity resistance. However, U.C. Salton was also more productive than Moapa even at the low salinity level level, especially toward the end of the study.

There was no difference between U.C. Salton and Moapa in stand count (Table 20), or leaf injury (Table 21). Evidently, any difference in salinity sensitivity between these two cultivars was not exhibited in terms of leaf symptoms, or in terms of leaf senescence as shown by the lack of a significant cultivar effect for % empty nodes (Table 15).

4. Chamber Effects

Alfalfa plants had greater growth and yield in outside plots than in ambient chambers, especially as the study progressed. This was despite the fact that outside plots actually had higher salinity levels than the ambient chambers. Plants tended to have higher % dry weight and lower height in outside plots than in ambient chambers on 9/5/85; higher fresh weights and lower heights than ambient chambers on 10/9/85 (Table 18); higher total fresh and dry weights, and lower % dry weights and % empty nodes (Table 19); and less leaf injury (Table 21) than ambient chambers on 11/18/85. However, as indicated earlier the differences between outside plots and ambient chambers on 11/18/85 are due to the added O_3 in the chambers and higher salinity in the outside plots, and not just the chamber itself.

The cumulative effect of the chambers over the course of four harvest seasons apparently was a large decrease in fresh and dry weights and stand count per plot compared to outside plots (Table 20). The decrease occurred to a similar extent not only in the ambient chambers, but also the filtered chambers. If filtering the air would have had an overall beneficial effect on alfalfa growth over four harvests, then it would have been expected that the stand count was greater in filtered chambers than outside plots. The primary factor affecting stand count appeared to be the lodging of plants in both filtered and ambient chambers before the 10/9 and 11/18/85 harvests. Lodging resulted in shading of smaller plants in the chambers, reducing their viability.

5. Interactions

There were a number of significant interactions among the major treatment factors of salinity, air, and cultivar. However, none of the interactions occurred consistently over all parameters or dates. Instead the interactions reflected particular differences in relative plant response to the factors at specific harvests. There also were scattered block x major factor, or block x replicate location interactions. These interactions did not follow any particular pattern and are not discussed here.

The interaction between salinity x O_3 (filtered vs. ambient chambers) was significant for total fresh weight at the 8/12 and 11/18/85 harvests and for % empty nodes at the 9/5/85 harvest (Table 15). Apparently, there was a trend toward a greater O_3-induced decrease in fresh weight for Moapa than U.C. Salton on 8/12/85, and greater decrease for U.C. Salton than Moapa on 11/18/85. The O_3-enhanced defoliation was reduced at the high salinity level in the ambient chambers on 9/5/85 (Table 17). A similar trend of a reduction in defoliation with the high salinity treatment occurred at the other harvests, but the results were not statistically significant.

There was a significant salinity x cultivar interaction only for % dry weight 9/5/85 at the harvest. Apparently % dry weight and height increased more with increasing salinity level for U.C. Salton than for Moapa (Table 18). A significant cultivar x air treatment occurred for total fresh weight on 8/12/85 (Table 16) and % empty nodes on 9/5/85 (Table 17). On 9/5/85 % empty nodes between filtered chambers and ambient chambers was greater for U.C. Salton than for Moapa.

An apparent salinity x chamber interaction occurred at the 9/5/85 harvest (Table 15). Both fresh and dry weight decreased more with increasing salinity levels in outside plots than in ambient chambers. However, this interaction may have been largely due to the higher soil salinity levels in the low, medium, and high salinity treatments in the outside plots than in corresponding ambient chamber plots; and not a true interaction.

Finally, there was a significant three factor (cultivar x salinity x air) interaction for total fresh weight on 8/12/85 (Table 15). The precise nature of this complex interaction was not well understood. Total

fresh weight was lowest with increasing salinity levels in both filtered and ambient + O_3 chambers of Moapa (Table 16).

D. Applicability of These Findings

1. Stress Interactions

These results indicate the complexity that can arise when studying the effects of interacting stresses on plants in the field. Open-top field chambers especially became an important confounding factor as the environment changed over the course of the growing season. The small differences in the environment between chambers and outside plots become much more significant with cooler temperatures or overcast weather as reported earlier for alfalfa (25), and lettuce or wheat (26,33).

The effects of small differences in the ambient environment on plants can become more important than other artificial environmental variables imposed in the chambers. For example, the alfalfa plants tended to be shorter and more rigid at higher salinity levels. This altered morphology reduced the tendency of plants to lodge in the chambers, resulting in potentially greater yields with higher salinity in chambers, but not outside. In addition, if filtered air results in healthier, more rapidly growing plants; then plants in the filtered air x low salinity treatment chamber may lodge the most and have the apparent lowest yield of any treatment. In contrast, plants in filtered air and low salinity treatments would likely have the highest yields when grown in the field without chambers.

Other stress interactions in chambers may produce similar results. For example, open-top chambers do not have dew formation at night during cool months. Thus acidic fog treatments at night result in deposition of applied fog directly to dry leaves in chambers, whereas fog would actually be diluted on outside leaves with preexisting fog. Such results have been documented in a current acidic fog study underway at U.C. Riverside.

2. Modification of Estimated Ozone Crop Losses by Salinity

This study indicated that salinity has a much larger effect on crop productivity than ambient O_3. The low salinity level represents a conductivity found in normal soils (<2 dS m^{-1}), whereas the medium and high salinity levels represent soils with salinity problems (>4 dS m^{-1})

(3,28). Thus the yield due to salinity at >5 dS m^{-1} in this study are representative of actual growing conditions in California.

If the production of a crop in a county or portion of a county is restricted by salinity, then the added loss of crop yield caused by O_3 would be negligible. If such geographical areas could be identified for specific crops, these areas could be assigned an estimated yield loss of 0 from O_3 regardless of the loss expected from the ambient O_3 data.

The study also indicated a lack of interaction between salinity and O_3 on crop productivity. If soil salinity was not great enough to have a significant effect on crop production in a specific area, then it is likely that the salinity would not modify the sensitivity of the crop to O_3. Thus, in these areas the available O_3 dose-yield loss equations for that crop would be used, without any modification of the estimated loss caused by salinity.

There were only limited levels of both factors available in this study with which to statistically evaluate salinity x O_3 interactions. If additional studies were to indicate an interaction between salinity and O_3 on yield losses, then the available dose-yield loss equations would have to be modified to either increase or decrease the estimated yield loss with a specific O_3 dose depending on soil salinity.

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